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A SCHEMA-BASED MODEL OF SITUATION AWARENESS: IMPLICATIONS FOR MEASURING SITUATION AWARENESS

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ABSTRACT

Measures of pilot situation awareness (SA) are needed in order to know whether new concepts in display design help pilots keep track of rapidly changing tactical situations. In order to measure SA, a theory of situation assessment is needed. In this paper, I summarize such a theory encompassing both a definition of SA and a model of situation assessment. SA is defined as the pilot's knowledge about a zone of interest at a given level of abstraction. Pilots develop this knowledge by sampling data from the environment and matching the sampled data to knowledge structures stored in long-term memory. Matched knowledge structures then provide the pilot's assessment of the situation and serve to guide his attention. A number of cognitive biases that result from the knowledge matching process are discussed, as are implications for partial report measures of situation awareness.

INTRODUCTION

Under the intense stress of combat, military pilots will need to keep track of a rapidly evolving tactical situation. Helping the pilot to maintain his knowledge of the situation from moment to moment, referred to as situation awareness (SA), has become a matter of considerable interest. Measures of pilot SA are needed in order to know whether new concepts in avionics and display design improve SA or not, but psychologists are only now beginning to explore whether and how SA can be measured. Two fundamental questions must be answered before appropriate measures can be developed: precisely what is situation awareness, and how do pilots maintain it. A clear definition of SA is needed because we do not know what to measure otherwise. A model of how pilots maintain SA is needed in order to suggest what kinds of measures will target SA and what kinds will miss the target all together.

In this paper, I will summarize a theory of situation assessment encompassing a definition of SA and a model of how SA is maintained. In the course of this summary, I will show how the theory accounts for certain well-known biases in human cognition.

WHAT IS SITUATION AWARENESS?

In order to define situation awareness, one should first define what a situation is. In this paper, I define a situation to be a set of processes that control events in the environment. At any given moment in time, objects in the environment will be in particular states and at particular spatial locations, but these states and locations are

constantly changing. Therefore, while momentary states of objects are critical to defining a given situation, those states are secondary to the processes that control them. Further, processes in the environment may themselves arise from higher order factors. In combat, for example, there will exist at least two opposing forces, each of which has its own set of goals. In order to achieve those goals, each force will have organized itself in a certain way and will have assigned certain functions to various members of the resulting organization. The processes of combat then arise from the interactions of functions between the two opposing forces.

A situation, then, can be defined at various levels of abstraction. At the highest level, the situation may be defined in terms of the goals of the human participants. At the lowest level, the situation may be defined in terms of the momentary states of objects in the environment. In between these two extremes, the situation may be defined in terms of the organizations, functions, or processes that translate goals into states.

Situation awareness, therefore, can be defined partly as the knowledge that results when attention is allocated to the environment at one or more levels of abstraction. Of course, one could also allocate attention to a particular area within the environment--what Endsley (1988) calls a "zone of interest". Endsley (1988) has defined zones of interest as concentric volumes of space surrounding the pilot throughout which he distributes his attention. But these zones need not be spatially defined. For example, the pilot's own aircraft could define one zone, his own flight could define a larger zone, and the overall battle may define yet a larger zone. Thus, situation awareness should more properly be said to result from the allocation of

attention to a zone of interest at least one level of abstraction. For convenience, I refer to the intersection of zones of interest with levels of abstraction as the "focal region". Assuming that attention is a scarce resource (Kahneman, 1973; Wickens, 1984), situation awareness should be better within a small focal region than within a large one (cf., Eriksen & Yeh, 1985).

A MODEL OF SITUATION ASSESSMENT

Defining situation awareness determines what is to be measured but does not suggest how it should be measured. For this latter purpose, a model of situation assessment is needed. Ideally, such a model will indicate what kinds of measurement operations will target SA and what kinds will miss the target altogether.

Some models of situation assessment stress that pilots develop and maintain a mental representation of the situation in working memory (Endsley, 1988). Because SA is maintained in working memory, these models predict that pilot SA should improve as the pilot's working memory capacity increases. Wickens, Stokes, Barnett, and Davis (1987) have recently provided evidence in support of this prediction. But a strictly increasing monotonic relation between working memory capacity and the quality of SA is expected only if all critical information about the situation must be represented in working memory at all times. This condition would exist only if the environment were the pilot's only source of information. But many theorists propose that recognized patterns among incoming sensory data may identify knowledge structures stored in long-term memory and that these identified structures are also a source of knowledge about the situation (Anderson, 1983; Rumelhart, 1984; Shank, 1982; Wyer & Srull, 1986). The knowledge structures in long-term memory go by different names, depending upon the theorist: associative networks (Anderson, 1983), memory organization packets (Shank, 1982), referent bins (Wyer & Srull, 1986), or schemata (Rumelhart, 1984).

If schemata can provide substantial information about a situation, then the pilot need not attend to every detail of the environment in order to have a reasonably complete assessment of the situation. Rather, he needs to have schemata that accurately fill in many of the details, and he needs to recognize patterns in the incoming sensory data adequate to identify these schemata. Once a schema has been identified, the pilot needs only to search the schema for items of information not currently in working memory.

When an appropriate schema is not found in long-term memory, then the pilot must resort to a backup procedure that greatly increases the load on working memory. This backup procedure has been described by Wyer and Srull (1986). Essentially, the pilot must attend to a larger amount of information in the environment, identify multiple schemata that may be appropriate, place information from these several schemata into working memory, and then integrate the information into a single result.

This model of situation assessment predicts that the relationship between working memory capacity and quality of SA is dependent on the completeness of the knowledge the pilot has stored in long-term memory. If that knowledge is sufficiently complete with respect to a particular focal region, then the quality of SA should be less sensitive to working memory capacity. This dependence on long-term memory suggests that working memory capacity should have a greater impact on the SA of novice pilots than of highly trained expert pilots.

THE MODEL IN OPERATION: COGNITIVE BIASES IN SITUATION ASSESSMENT

Although schemata can facilitate situation assessment and relieve the load on working memory, they can also lead to biases that degrade the quality of situation assessment. These biases are representativeness, availability, the confirmation bias, cue salience, and the "as if" heuristic (see Kahneman, Slovic, & Tversky, 1982; Wickens, 1984; Wickens et al., 1987). These heuristics and biases can be divided into two groups: those that operate when incoming data match some schema, and those that operate when no match is found. Representativeness, availability, and the confirmation bias belong to the first group and are natural consequences of the situation assessment model. Cue salience and the "as if" heuristic belong to the second group and result from the demands of the backup assessment process on limited working memory and attentional resources.

"Representativeness" is defined in Kahneman et al. as the process of matching the pattern of incoming data with a typical pattern for a particular situation stored in long-term memory. Such a matching process is not a computational short-cut as it is sometimes said to be (Wickens et al., 1988) but is instead the central mechanism of situation assessment. Nevertheless, that such pattern matches can sometimes lead to errors in assessment seems indisputable.

One way such matches can go wrong is captured by the availability heuristic.

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"Availability" occurs when pilots select the most accessible schema rather than the "best" schema. Within the model, availability results when two or more schemas identify themselves as matching in-coming data and the schema with the strongest level of activation provides the pilot with his situation assessment. Activation strength may be high for several reasons. One is that activation strength should increase as the goodness-of-fit between the data and the schema increases. Another is that a schema may have been primed by earlier events and so already have a high base-line level of activation. If so, then a partial match may result in a higher level of activation than that found in another, unprimed schema where the match was actually better.

The confirmation bias is defined as the tendency to attend only to those sources of information that confirm our previous beliefs. In the present model, the confirmation bias results whenever a schema is activated. The schema directs the pilot's attention to those cues that are relevant assuming that the event represented by the schema is in fact in progress. When the correct schema has been activated, this attentional guidance is beneficial; but if an incorrect schema has been activated, then such guidance can lead to a cascade of assessment errors as one error leads to another.

Cue salience results when activated schemata are not adequate to direct the pilot's attention or when working memory is too overloaded to retain the attentional guidance provided by a schema. In the absence of such attentional guidance, control of the pilot's attention is likely to shift to the external environment. The physical salience of environmental cues may then become the dominant factor guiding the pilot's allocation of attention (cf., Wallsten, 1980).

The so-called "as-if" heuristic also comes into play in the absence of adequate schemata. When incoming data do not match a single schemata, then the data are broken down into subsets and these subsets are then matched to schemata. In the extreme case, each data item in the subset would be matched to a different schema, and the schemata would then serve only to interpret each individual item. The result is that information from multiple schemata will have to be integrated in order to provide a coherent assessment of the situation. In arriving at this assessment, the relative contribution of each item of information should be weighted so that it contributes to the assessment appropriately. But in the absence of a single schema to assign these weights, any weights assigned by the pilot would be arbitrary. Because the simplest set of

arbitrary weights is the set in which all weights are equal, pilots weight each item of information equally. That is, pilots treat the information items "as if" each had the same weight.

IMPLICATIONS OF THE MODEL: MEASURING SITUATION AWARENESS

An important aspect of the model is that once the pilot has achieved an assessment of the situation, that assessment is stored with the schema from which it was derived. If the assessment was integrated from information from multiple schemata, then a new schema is created and stored in long-term memory. At that point, the assessment may no longer be needed in working memory and so may be discarded (see Wyer & Srull, 1986, for a discussion of similar processes). This particular feature of the model has important implications for how SA can be measured, as will now be seen.

Any direct measure of SA will determine what aspects of the situation the pilot has stored in either working or long-term memory. That is, one could ask the pilot for particular kinds of information and then see if he can provide them. Because situation assessments are stored in long-term memory once they have been reached, it will generally not be possible to tell whether the pilot provided the information from working or long-term memory. But because situation assessments may not be retained in working memory once they are no longer needed, it is safest to assume that information is provided from long-term memory. This assumption might seem to suggest that SA could be measured by having pilots recall the details of a mission after the mission had been completed, an approach advocated by Whitaker and Klein (1988) and Kibby (1988). But data on serial position effects suggest that such an approach would measure pilot SA reliably only for events occurring late in the mission (see Tarpy & Mayer, 1978, for a review).

An alternative to post-mission recall is recall during the mission, an approach advocated by Endsley (1988) and Marshak, Kuperman, Ramsey, and Wilson (1987). At various points during the mission, the pilot is asked to report on certain but not all aspects of the mission. For this reason, the approach may be called a partial report procedure. Asking the pilot to recall information about an event during the time that the event is taking place raises certain procedural difficulties. First, the pilot does not need to recall the information if it is currently available in the environment. Therefore, Endsley and Marshak et al. have suggested blanking all displays that might convey the information in question to the pilot. Such a procedure is impossible or at

least extremely dangerous in actual airborne missions and so is used only in simulated missions. Further, to ensure that responding to the memory probe does not interfere with the pilot's mission performance, the simulation is frozen for the probe and then resumed following the pilot's response. A number of practical issues raised by this procedure have been discussed by Endsley (1988) and need not be repeated here.

A theoretical problem with the partial report procedure arises if recall is assumed to be from long-term memory. Essentially, the pilot has to search for the schema in which the relevant assessment was stored, and he has to base this search on the question that was asked. Suppose that the pilot is asked to report the spatial location of a particular enemy aircraft. Now imagine that when the location of that aircraft was noticed, the pilot was trying to determine that aircraft's objectives. Then, the aircraft's location will be stored with a "mission objectives" schema. But the question does not ask for the aircraft objectives, and so the pilot will not search for an objectives schema. As a result, the pilot may be unable to retrieve the aircraft's location even though he noticed and stored it. This theoretical difficulty may not discredit the partial report procedure, but it does suggest that care must be taken in constructing the questions that are to be asked.

Finally, the model suggests that measuring the load on working memory imposed by situation assessment may be as important as measuring SA itself. If pilots attain adequate SA but only at the cost of a high load on working memory, then they would be vulnerable to "losing" their SA if the demands of the mission on working memory were to increase. One way to measure the load on working memory would be by means of a secondary memory span task. Such a task could easily be integrated into the partial report method of measuring SA. Performance on the memory span task in combination with the partial report measure would then provide a measure of the pilot's SA and what it cost him to attain it.

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